Research on Optimal Scheduling Model and Peak Regulating Strategy of Micro Energy Network Based on TOU Policy

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Abstract. Micro energy network, as an important form of energy Internet, is one of the development trend of the future energy system. The frame of micro energy network is proposed using the micro energy network in Qingdao as an example. The optimal scheduling model of micro energy network based on Time-of-use (TOU) policy, with the minimum energy cost as objective function, is built in the paper. The model is solved by nonlinear optimization method and the output of the equipment in the micro energy network is obtained to meet the different daily load demands. According to the optimized results, the peak regulating strategy is proposed. The result shows that the optimal scheduling model of micro energy network based on TOU policy can improve the economy and make micro energy network play a great role in ‘cut peak and fill valley’.

Introduction

In order to solve the problems of energy shortage, environmental deterioration and low energy conversion, more and more countries in the world begin to readjust their energy structure, looking for new ways of energy development to improve the energy utilization efficiency [1-3]. Micro energy network is the basic unit and an important part of the energy Internet, with the features of energy interconnection, transformation, coupling and storage. The application of micro energy network can realize cascade utilization of energy and the coupling of multiple energy sources to increase the energy efficiency and reduce pollution gas and greenhouse gas emission.

At present, there are some researches on modeling, planning and energy management of multi energy systems at home and abroad. Reference [4] gives a general model of heat transmission network for multi area integrated energy system. And an optimal mixed integer linear programming model with heat supply network is established based on the operation optimization model of the Combined Cooling Heating and Power System (CCHP). Reference [5] provides a modeling method for a micro gas turbine integrated energy system. Reference [6] establishes an optimal operation model of the CCHP system with new energy generating equipment including fans and photovoltaic cells, focusing on the randomness of new energy generation and the fluctuation characteristics of the load. Reference [7-9] proposes a planning model of the equipment in the combined heat and power (CHP) system and genetic algorithm, Benders decomposition and particle swarm optimization are used to solve the model. The CCHP is connected with variety of equipment in [10], and the capacity allocation of the power sources in the system is computed to meet the demand of the economic optimality. Researches on day ahead schedule optimal dispatch of the system consisting of CCHP and wind power are present in [11], and it can effectively solve the problem of massive wind power curtailment when the heat output is large. The economic dispatch models of microgrid consisting of CCHP are constructed from different perspectives in [12-15] and solved by PSO algorithm. But these energy managements mentioned above focus on the multi energy system itself and there is no interaction between multi energy systems and power grids or other energy systems. Meanwhile, the peak regulating strategy of micro energy network has not been put forward yet.
According to the optimal scheduling model based on TOU policy, the effectiveness of the micro energy network in the peak load regulation of power grid is discussed. And peak regulating strategy of micro energy network is proposed according to the optimization results to realize the positive interaction between the micro energy network and the power grid.

The Structure of the Micro Energy Network

The micro energy network in this paper includes 4 forms of energy: cooling, heat, electricity and gas. And the structure of the micro energy network is shown in Figure 1.

![Figure 1. Schematic diagram of energy supply structure of micro energy network.](image)

Taking the micro energy network in Qingdao as an example, the price of natural gas is 4 yuan / Nm$^3$, and the TOU policy is shown in Figure 2.

![Figure 2. TOU policy of the system.](image)

Optimal Scheduling Model of Micro Energy Network

The three elements of the optimal models are the objective function, constrains and the decision variables. The general form is as followed.

$$\min f(x)$$

s.t. $h_i(x) = 0, i = 1, \ldots, m$

$$g_j(x) \leq 0, j = 1, \ldots, l$$

$$x \in D \subseteq R^n$$

The optimal scheduling model of the micro energy network can be written in the general form as followed.
\[
\text{min cost} = \sum_{i=1}^{24} \left( E_{\text{Buy}}(i) \cdot Q_G(i) + E_G(i) \cdot Q_{\text{Gas}} - E_{\text{sell}}(i) \cdot Q_S(i) \right)
\]

\textit{s.t.}
\[E_{\text{CCHP}} = -0.006347E_G^2 + 4.442E_G - 127\]
\[Q_{\text{CCHP}} = -0.002222E_G^2 + 3.263E_G - 73.83\]
\[C_{\text{CCHP}} = \text{COP}Q_{\text{AR}}\]
\[E_{\text{CCHP}} + E_{\text{PV}} + E_{\text{Buy}} + E_{\text{out}} - E_{\text{sell}} = E_{\text{load}} + E_{\text{pump}} + E_{\text{in}}\]
\[Q_{\text{load}} + Q_{\text{in}} = Q_{\text{CCHP}} + Q_{\text{pump}} + Q_{\text{fr}} + Q_{\text{out}} + Q_{\text{boi}}\]
\[0.5P_{\text{rated}} \leq P \leq P_{\text{rated}}\]
\[E_{\text{min}} \leq E_{\text{EES}}(t) \leq E_{\text{max}}\]
\[E_{\text{min}} \leq E_{\text{HS}}(t) \leq E_{\text{max}}\]
\[E_{\text{min}} \leq E_{\text{CS}}(t) \leq E_{\text{max}}\]

\[E = [E_{\text{Buy}}, E_{\text{sell}}, E_{\text{in}}, E_{\text{out}}, E_{\text{CCHP}}, E_{\text{pump}}];\]
\[Q = [Q_{\text{in}}, Q_{\text{out}}, Q_{\text{CCHP}}, Q_{\text{pump}}, Q_{\text{fr}}, Q_{\text{boi}}];\]

where, cost is the energy cost of the typical day, yuan; \(E_{\text{CCHP}}, Q_{\text{CCHP}}\) and \(C_{\text{CCHP}}\) are the power/heat/cooling generation of the CCHP system, kW·h; \(E_G\) is the gas supplied, Nm³; COP is the performance coefficient, related to the operating conditions; \(E_{\text{Buy}}\) and \(E_{\text{Sell}}\) are the electricity quantity purchased and sold by the micro energy grid, kW·h; \(E_{\text{in}}\) and \(E_{\text{out}}\) are the charge and discharge quantity of the electric storage system, kW·h; \(E_{\text{pump}}\) is the electricity consumption of the heat pump, kW·h; \(E_{\text{PV}}\) is the power generation of the PV system, kW·h; \(E_{\text{load}}\) is the electricity load of the system, kW·h; \(Q_{\text{in}}\) and \(Q_{\text{out}}\) are cooling/heat storage and release quantity of the cool/heat storage system, kW·h; \(Q_{\text{pump}}\) is the cooling/heat production of the air source heat pump, kW·h; \(Q_{\text{fr}}\) is the cooling production of the screw chiller, kW·h; \(Q_{\text{boi}}\) is the heat production of the gas-fired boiler, kW·h; \(Q_{\text{load}}\) is the heat/cooling load of the system, kW·h.

**Case Study**

Using the micro energy network in Qingdao as an example, the output of the equipment and the energy cost are studied in the case of micro energy network without storage system and with storage system. Referring to the history data, the output of the PV system on the typical day can be obtained, shown in Fig 3. The rated powers of the equipment are shown in Table II.

![Figure 3. Power generation of the PV system on the typical day.](image-url)
Table 1. Parameters of major equipment.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Rated power[kW]</th>
</tr>
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<tbody>
<tr>
<td>Micro gas turbine</td>
<td>625×3</td>
</tr>
<tr>
<td>Waste-heat boiler</td>
<td>2025×1</td>
</tr>
<tr>
<td>LiBr absorption chiller</td>
<td>1764×1</td>
</tr>
<tr>
<td>Air source heat pump</td>
<td>350×1</td>
</tr>
<tr>
<td>PV module</td>
<td>0.125×27520</td>
</tr>
<tr>
<td>Screw chiller</td>
<td>2060×1</td>
</tr>
<tr>
<td>Gas-fired boiler</td>
<td>3200×1</td>
</tr>
<tr>
<td>Ice storage bucket</td>
<td>4800×1</td>
</tr>
<tr>
<td>Heat storage boiler</td>
<td>4800×1</td>
</tr>
<tr>
<td>Battery</td>
<td>500×1</td>
</tr>
</tbody>
</table>

Matlab optimization toolbox is used to solve the optimal model and the energy supply of the equipment on the typical day can be obtained in different cases. The impact of the optimal operation of micro energy network on peak load regulation is analyzed and the role of the storage system in the micro energy network is also discussed.

**Optimal Operation of the Micro Energy Network without Storage System**

The output of the equipment in the micro energy network without storage system on the typical day in winter is show in Fig 4. The CCHP system has obvious economic advantages during peak period. It can be seen from the comparison between the power purchase curve and the load curve that the optimization model proposed in this paper can shift electricity from peak periods to off peak periods. It contributes to the smooth and safe operation of the power system.

![Figure 4. Output of the micro energy network without storage system on the winter typical day.](image)

The output of the equipment in the micro energy network without storage systems on the typical day in summer is show in Fig 5. The price of the electricity generated by the natural gas is higher than that in the power grid in summer. The micro energy network chooses to shut down the CCHP system and uses the power of the power grid. As a result, the micro energy network cannot cut the peak to the most satisfactory level at summer nights.
Optimal Operation of the Micro Energy Network with Storage System

The output of the equipment in the micro energy network with the storage system on the typical day in winter is show in Fig 6. The negative value in the figure indicates that the energy storage system is in the energy storage state. After the energy storage system added to the network, the heat supply can meet the needs of the system at the heat peak, and it can better suppress the peak power consumption at night.

The output of the equipment in the micro energy network with the storage system on the typical day in winter is show in Fig 7. The negative value in the figure indicates that the energy storage system is in the energy storage state. After the energy storage system added to the network, when the district cooling is stopped at night, the CCHP system can still be operated economically and be used for peak regulation.
Table III is about the change of the operation cost of the micro energy network before and after the energy storage system is added. It can be seen from the table that the electricity is stored when the price is low and it is released when the price is high. At the same time, the excess cooling / heat energy generated by the CCHP system is stored during the peak period, which relieves the energy supply pressure of the system and reduces the cost of the user's energy consumption.

Table 2. Operation cost of micro energy network before and after energy storage system added.

<table>
<thead>
<tr>
<th>Season</th>
<th>Storage system</th>
<th>Cost [yuan]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>no</td>
<td>99097.64</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>96185.57</td>
</tr>
<tr>
<td>Summer</td>
<td>no</td>
<td>71635.04</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>68733.22</td>
</tr>
</tbody>
</table>

To sum up, the micro energy network is conducive to the comprehensive utilization of various energy sources and relieves the pressure of energy supply during the peak period. The storage system stores energy during the off-peak period to reduce the cost and realize the optimal operation of the system. The micro energy network reduces the power supply pressure of the power grid and keeps the reliability and stability of electricity supply.

Based on the above optimization results, the peak regulating strategy of micro energy network is summarized, as shown in Fig 8.

(a) The peak regulating strategy of micro energy network during peak period
Can the pump satisfy the cooling/heat load
Pump fills the vacancy, the power used by the pump added to the electricity load

Can the output of the CCHP and PV satisfy the cooling/heat load
Superfluous electricity stored in the storage system
Superfluous electricity fed back to the power grid
Power exchange with power grid

Can the output of the PV satisfy the cooling/heat load
Superfluous electricity stored in the storage system
Superfluous electricity fed back to the power grid
Power exchange with power grid

Full charge of electric storage system

(b) The peak regulating strategy of micro energy network during off-peak period

Figure 8. Peak regulating strategy of micro energy network.

Conclusion
The micro energy network in Qingdao is used as an example of the micro energy network in this paper. Based on the TOU policy, the optimal scheduling model of the micro energy network is constructed. According to the rated power of the equipment and loads of the system, the optimal model is solved by the optimization toolbox in MATLAB, and the output of the equipment in the micro energy network is obtained. The results show that the optimal energy supply scheme can be obtained by solving the model. The energy supply scheme can optimize the energy distribution in the micro energy network, shifting electricity from peak periods to off peak periods, and improves the power supply reliability of the power system. Furthermore, the storage system added to the micro energy system can improve the peaking operation ability of the micro energy network and improve the flexibility and economy of the system operation. In the end, according to the results, the peak regulating strategy of micro energy network is proposed.

References


